Claims

1. Method for decoding a signal ($y(t)$) sent over a bandwidth-expanding communication channel, comprising the step of sampling the received signal ($y(t)$) with a sampling frequency (f_s) lower than the sampling frequency given by the Shannon theorem, but greater than the rate of innovation (ρ) of said received signal ($y(t)$), for generating a set of sampled values ($y(nT_s)$).

2. Method according to claim 1, further comprising the preliminary step of filtering said received signal ($y(t)$) with a filter (f).

3. Method according to claim 2, wherein said filter (f) is a lowpass filter.

4. Method according to claim 3, wherein said filter (f) is a sinc filter.

5. Method according to claim 3, wherein said filter (f) is a Gaussian filter.

6. Method according to claim 5 wherein said bandwidth-expanding communication channel comprises a multipath fading transmission channel (c).

7. Method according to claim 1, wherein said bandwidth-expanding communication channel is a CDMA system.

8. Method according to claim 7, wherein said sampling frequency ($1/T_s$) is lower than the chip rate ($1/T_c$) of said received signal ($y(t)$), but greater than its information rate (K/T_b).

9. Method according to claim 7, wherein said sent signal includes a plurality of training sequences (**b_{kt}**) each encoded with a user specific coding sequence ($s_k(t)$) and transmitted by said users (k), said method further comprising the steps of

computing a set of spectral values ($Y[m]$) corresponding to said received signal ($y(t)$) from said set of sampled values ($y(nT_s)$),

recovering spectral values ($S_k[m]$) corresponding to each of said user specific coding sequence ($s_k(t)$),

retrieving the delays ($\tau_k^{(1)}$) and the amplitude attenuations ($a_k^{(1)}$) induced by said communication channel on said sent signal ($y(t)$), from said set of spectral values ($Y[m]$) corresponding to said received signal ($y(t)$) and from said spectral values ($S_k[m]$) corresponding to each of said user specific coding sequence ($s_k(t)$).

10. Method according to claim 9, wherein the step of retrieving said delays delays ($\tau_k^{(1)}$) and said amplitude attenuations ($a_k^{(1)}$) includes solving a series of one-dimensional estimation problems, the size of each said one-dimensional estimation problem being equal to the number of said sampled values ($y(nT_s)$) generated during one symbol duration (T_b).

11. Method according to claim 10, wherein said series of one-dimensional equation systems is derived from said spectral values ($Y[m]$) of said received signal ($y(t)$), said spectral values ($S_k[m]$) of each of said user specific coding sequence ($s_k(t)$) and the value of the bits ($b_k^{(h)}$) of said training sequences (**b_{kt}**).

12. Method according to claim 11, further comprising the steps of

decoding a second sent signal ($y(t)$) including a

plurality of symbols (b_k) each encoded with said user specific coding sequence ($s_k(t)$) and transmitted by said users (k),

sampling said second sent signal ($y(t)$) with a sampling frequency lower than the sampling frequency given by the Shannon theorem, but greater than the rate of innovation (ρ) of said second sent signal ($y(t)$), for generating a second set of sampled values ($y(nT_s)$).

13. Method according to claim 12, further comprising the steps of running a multiuser detection scheme using said second set of sampled values ($y(nT_s)$) and previously computed said delays ($\tau_k^{(1)}$) and said amplitude attenuations ($a_k^{(1)}$) for estimating the value of the symbol (b_k) sent by each said user (k).

14. Method according to claim 13, wherein said multiuser detection scheme is a decorrelating detection scheme.

15. Method according to claim 12, wherein said multiuser detection scheme is a minimum mean-square error detection scheme.

16. Method according to claim 7, wherein said sent signal includes a plurality of symbols (b_k) each encoded with said user specific coding sequence ($s_k(t)$) and transmitted by said users (k), said method further comprising the steps of

running a multiuser detection scheme using known delays ($\tau_k^{(1)}$) and amplitude attenuations ($a_k^{(1)}$) induced by said communication signal on said sent signal ($y(t)$) and using said set of sampled values ($y(nT_s)$) and for estimating the value of the symbol (b_k) sent by each said user (k).

17. Method according to claim 16, wherein said multiuser detection scheme is a decorrelating detection scheme.

18. Method according to claim 15, wherein said multiuser detection scheme is a minimum mean-square error detection scheme.

19. Method according to claim 7, wherein said sent signal ($y(t)$) includes a plurality of training sequences ($\mathbf{b}_{kt}$) each encoded with a user specific coding sequence ($s_k(t)$) and transmitted by said users (k), said method further comprising the steps of

computing a set of spectral values ($Y[m]$) of said received signal ($y(t)$) from said set of sampled values ($y(nT_s)$),

computing a set of channel dependant values ($\mathbf{C}$) from said set of spectral values ($Y[m]$) and said training sequences ($\mathbf{b}_{kt}$),

decoding a second sent signal ($y(t)$) including a plurality of symbols (b_k) each encoded with said user specific coding sequence ($s_k(t)$) and transmitted by said users (k),

sampling said second sent signal ($y(t)$) with a sampling frequency lower than the sampling frequency given by the Shannon theorem, but greater than the rate of innovation (ρ) of said second sent signal ($y(t)$), for generating a second set of sampled values ($y(nT_s)$)

retrieving the value of the symbol (b_k) sent by each said user (k) by solving a linear matrix system including said second set of sampled values ($y(nT_s)$) and said set of channel dependant values ($\mathbf{C}$).

20. Method according to claim 7, wherein said sent signal ($y(t)$) includes a plurality of symbols (b_k) each

encoded with said user specific coding sequence ($s_k(t)$) and transmitted by said users (k), said user specific coding sequence ($s_k(t)$) being chosen such that, when filtered with a lowpass filter (f), it is orthogonal to any other user's specific coding sequence ($s_k(t)$) used in said communication channel and filtered with said lowpass filter (f), said method further comprising the steps of

sampling said sent signal ($y(t)$) with a sampling frequency lower than the sampling frequency given by the Shannon theorem, but greater than the rate of innovation (ρ) of said sent signal ($y(t)$), for generating a set of sampled values ($y(nT_s)$)

filtering said set of sampled values ($y(nT_s)$) with a bank of matched filters, each filter being matched to said user specific coding sequence ($s_k(t)$) filtered with said lowpass filter (f), for estimating the value of the symbol (b_k) sent by each said user (k).

21. Method according to claim 7, wherein said communication channel comprises an array of antennas (i).

22. Method according to claim 21, wherein said sent signal ($y(t)$) is the superposition of a plurality of training sequences ($\mathbf{b_{kt}}$) each encoded with a user specific coding sequence ($s_k(t)$) and transmitted by said users (k), said method further comprising the steps of

sampling the received signals ($y_i(t)$) received by each antenna (i) in the antenna array with a sampling frequency (f_s) lower than the sampling frequency given by the Shannon theorem, but greater than the rate of innovation (ρ) of said received signals ($y_i(t)$), for generating sets of sampled values ($y_i(nT_s)$)

computing sets of spectral values ($Y_i[m]$) of said received signals ($y_i(t)$) from said sets of sampled values ($y_i(nT_s)$),

recovering the spectral values ($S_k[m]$) of each of said user specific coding sequence ($s_k(t)$),

retrieving the delays ($\tau_k^{(1)}$), the amplitude attenuations ($a_k^{(1)}$) and the directions of arrival ($\theta_k^{(1)}$) induced by said communication channel on said sent signal ($y(t)$) from said sets of spectral values ($Y_i[m]$) corresponding to said received signals ($y_i(t)$) and from said spectral values ($S_k[m]$) corresponding to each of said user specific coding sequence ($s_k(t)$).

23. Method according to claim 22, wherein the step of retrieving said delays delays ($\tau_k^{(1)}$), said amplitude attenuations ($a_k^{(1)}$) and said directions of arrival ($\theta_k^{(1)}$) includes solving a series of two-dimensional estimation problems, the size of each said two-dimensional estimation problem being equal to the number of said sampled values ($y_i(nT_s)$) generated during one symbol duration (T_b).

24. Method according to claim 23, wherein said series of two-dimensional equation systems is derived from said spectral values ($Y_i[m]$) of said received signal ($y_i(t)$), said spectral values ($S_k[m]$) of each of said user specific coding sequence ($s_k(t)$) and the value of the bits ($b_k^{(h)}$) of said training sequences ($\mathbf{b_{kt}}$).

25. Method according to claim 24, further comprising the steps of

decoding a second sent signal ($y(t)$) including a plurality of symbols (b_k) each encoded with said user specific coding sequence ($s_k(t)$) and transmitted by said users (k),

orienting the beams of said array of antennas (i) towards previously determined said arrival directions ($\theta_k^{(1)}$),

sampling said second sent signal ($y(t)$) with a

sampling frequency lower than the sampling frequency given by the Shannon theorem, but greater than the rate of innovation (ρ) of said second sent signal ($y(t)$), for generating a second set of sampled values ($y(nT_s)$).

26. Method according to claim 25, further comprising the steps of running a 2D-RAKE detection scheme using said second set of sampled values ($y(nT_s)$) and previously computed said delays ($\tau_k^{(1)}$) and said amplitude attenuations ($a_k^{(1)}$) for estimating the value of the symbol (b_k) sent by each said user (k).

27. Method according to claim 1, wherein said bandwidth-expanding communication channel is an Ultra Wideband (UWB) communication system.

28. Computer program product directly loadable into the internal memory of a digital processing system and comprising software code portions for performing the method of claim 1 when said product is run by said digital processing system.

29. Receiver for decoding a signal ($y(t)$) sent over a bandwidth-expanding communication system according to the method of claim 1.

30. Receiver according to claim 29, comprising a memory for storing said spectral values ($S_k[m]$) of said signature sequences ($s_k(t)$).

31. Set of at least two encoders for use with a receiver according to claim 29, each encoder (50) of said set of encoders being assigned at least one training sequence (b_{kt}) to be sent over a bandwidth-expanding channel during a training phase (30), wherein said at least one

training sequence (b_{kt}) is chosen such that it is linearly independent from any other training sequence (b_{kt}) assigned to any other encoder (50) of said set of encoders.

32. Set of at least two encoders according to claim 31, each said encoder (50) being assigned at least two said training sequences (b_{kt}), wherein each said encoder (50) is designed to select from said at least two training sequences (b_{kt}) the training sequence (b_{kt}) to be sent during said training phase (30).

33. Set of at least two encoders according to claim 31, each said encoder (50) further being assigned a specific coding sequence ($s_k(t)$) for coding a signal ($x(t)$) to be sent over said bandwidth-expanding channel, wherein said coding sequence ($s_k(t)$) is chosen such that, when filtered with a lowpass filter (f), it is orthogonal to any specific coding sequence ($s_k(t)$) assigned to any other encoder (50) of said set of encoders filtered with said lowpass filter (f).